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Large-scale, high-resolution wind resource mapping for wind farm planning and development in South Africa

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Summary

Numerical wind atlas data at 5 km resolution have been used to map the wind resources of the *Wind Atlas for South Africa* (WASA) domain in great detail: mean wind speed, mean wind power density, elevation and ruggedness index for every 250 metres over an area of 350,000 square kilometres.

The wind-climatological inputs to the wind resource mapping are wind atlas data sets derived from mesoscale modelling using the Karlsruhe Atmospheric Mesoscale Model (KAMM). The topographical inputs to the microscale modelling are 20-m digital height contours from 1:50,000 South African topographical maps and vector-format land surface roughness maps based on the USGS Global Land Cover Characteristics database (GLCC). A transformation table was used to relate land cover to roughness length.

The detailed resource map has been verified at ten mast locations where high-quality wind measurements are available. Overall, the resource map seems to underestimate the wind resources by about 12%; half of this bias is due to the wind-climatological inputs, the other half is related to the topographical descriptions. However, the exact discrepancy is not critical for most of the intended applications.

The detailed wind resource estimates are designed for national and provincial planning and strategic environmental impact assessment for wind power in South Africa and the results have therefore been made available in common GIS formats. The database of results is in the public domain and can be downloaded from the WASA web site. An updated version of the database will be available in the spring of 2014.

1 Introduction

Wind Atlas for South Africa (WASA) is a 4-year project with the objective to develop and employ numerical wind atlas methods and develop capacity to enable planning for large-scale exploitation of wind power in South Africa.

The WASA project contains work packages for i) Mesoscale modelling, ii) Wind measurements, iii) Microscale modelling, iv) Wind atlas application, v) Extreme wind atlas, and vi) Documentation and dissemination. The WASA study area is shown in Figure 1, including the location and name of the 10 dedicated wind measurement stations [1].

Figure 1. Overview map of the southernmost part of South Africa, showing the location of the 10 meteorological masts referred to in the text and the Wind Atlas for South Africa study area (Image © 2012 Tele Atlas, Data SIO, NOAA, US Navy, NGA, GEBCO, Afri-GIS (Pty) Ltd., and Google Inc.)

The study area is defined as the 'coastal areas of Western, Eastern and Northern Cape provinces', where coastal is interpreted here as referring to the land area between the coastline and the Great Escarpment – the plateau edge in South Africa which separates the highland interior from the lower coastal areas.

One of the sub-tasks of the WASA project is a "Microscale resource map for 30-50% of the modelled areas in the three provinces, incl. integration as GIS layer". This paper is a description of the methodology applied and results obtained for this task. In the end, all 100% of the project domain was covered with a microscale resource map.

The approach used for the wind resource mapping is based on the numerical wind atlas methodology; in the present case what is known as the KAMM/WAsP methodology [2]. A numerical wind atlas is produced for the entire study area by downscaling reanalysis wind climatologies (using KAMM). The numerical wind atlas is subsequently used as input to microscale modelling at high resolution over the entire domain (using WAsP), see also [2, 3, 4, 5].

2 Methodology

The first WASA verified numerical wind atlas is based on statistical-dynamical downscaling method (KAMM/WAsP method) and has provided wind atlas data sets at 5 km horizontal spacing over the Wind Atlas for South Africa domain: Western Cape and parts of Eastern and Northern Cape provinces.

The generalised wind climatologies at each model node consist of wind roses and wind speed distributions for a number of standard land cover types and heights above ground level. The first verified numerical wind atlas was obtained by downscaling 30 years of NCEP/NCAR reanalysis data using the Karlsruhe Atmospheric Mesoscale Model.

The wind atlas data sets are used together with detailed elevation and land cover maps to model the wind resources of a 350,000 square kilometre area with a distance of 250 meters between calculation points. The microscale model used here is WAsP 10 [6].

The topographical data used for the high-resolution modelling are 20-m digital height contours from 1:50,000 South African topographical maps and land cover information from the USGS Global Land Cover Characteristics database (GLCC). These data sets were readily available at the time of modelling, but will be improved at a later stage.

For the modelling of wind power density, the air density at every modelling node needs to be known. This can be modelled using a standard atmosphere or a simpler expression fitted to the air density measurements at the 10 meteorological masts, see Figure 2.

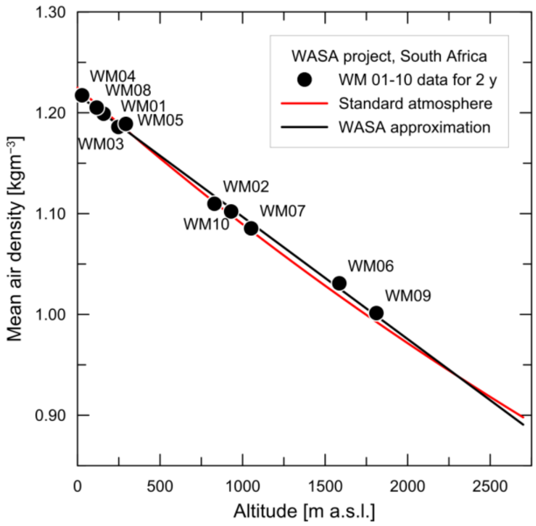

Figure 2. Mean air density at the 10 WASA mast sites plotted versus site (barometer) altitude [7]. Also shown are the standard atmosphere and the approximation used in the WASA project.

The microscale modelling was carried out using a special implementation of the WAsP models known as the WAsP Resource Mapping System. This implementation employs databases of wind climates, elevation maps, and roughness maps rather than simple data files. In addition, the operation of the WAsP models has been automated and utilises distributed computing to speed up the calculation tasks. The wind atlas data are further interpolated to every prediction site in order to obtain a continuous wind resource map. The WAsP engine is run in its standard configuration.

3 Results

The outputs of the microscale modelling are 250-m grids of long-term mean wind speed [ms^{-1}] and mean power density [Wm^{-2}], terrain surface elevation [m a.s.l.] and terrain ruggedness (RIX index). Results are calculated for 100 m above ground level and are provided in ArcGIS ASC grid format. Figure 3 shows the modelled mean wind speed at 100 m a.g.l. in the WASA domain.

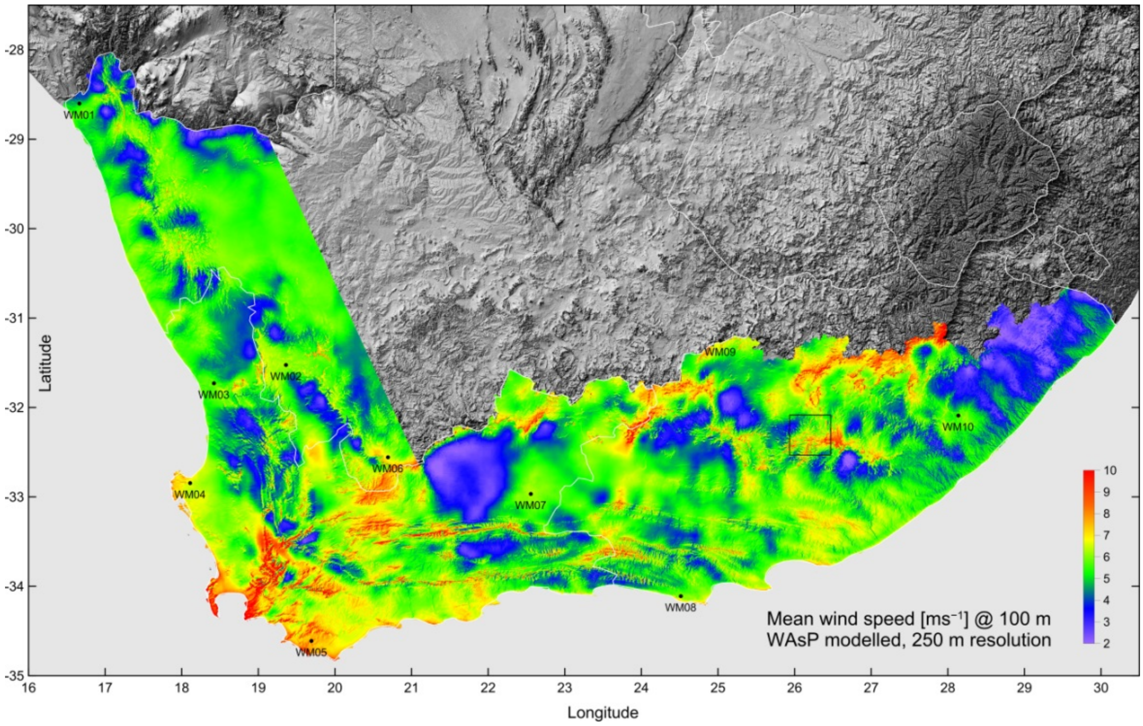

Figure 3. Modelled mean wind speed at 100 m a.g.l. in the WASA domain. The results were obtained using a WAsP 10 engine, with model calculations done for every 250 m.

A 50×50 km^2 area is marked with a black square in Figure 3 (around 26°E, 32.5°S); this area is shown in detail in Figure 4.

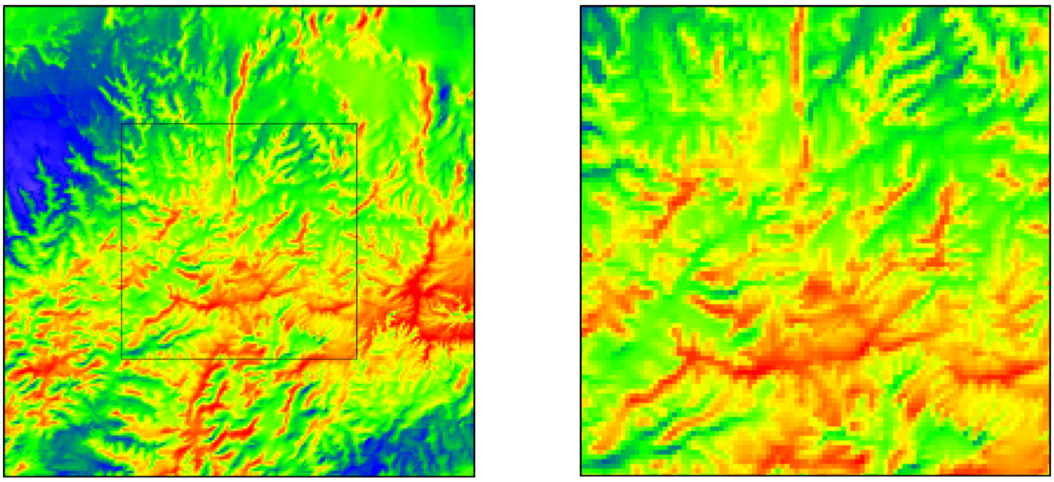

Figure 4. Modelled mean wind speed 100 m a.g.l. in 50×50 and 25×25 km^2 areas, respectively. The outline of the 50×50 km^2 square is also shown in Figure 3.

Figure 3 shows the modelled mean wind power density at 100 m a.g.l. in the domain. The power density is calculated with a site-specific air density as was described above.

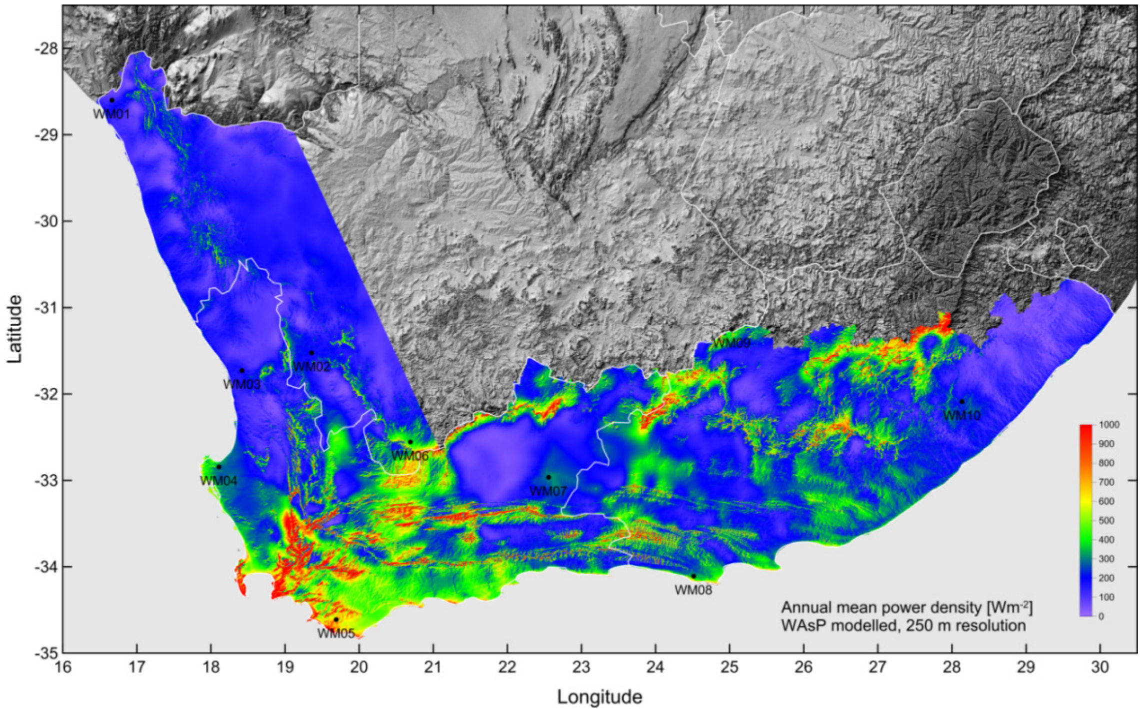

Figure 5. Modelled mean wind power density at 100 m a.g.l. in the WASA domain. The results were obtained using WAsP 10, with model calculations done for every 250 m.

In addition to the wind resource maps, the database also contains terrain surface elevation and ruggedness index for each modelling point, see Figure 6.

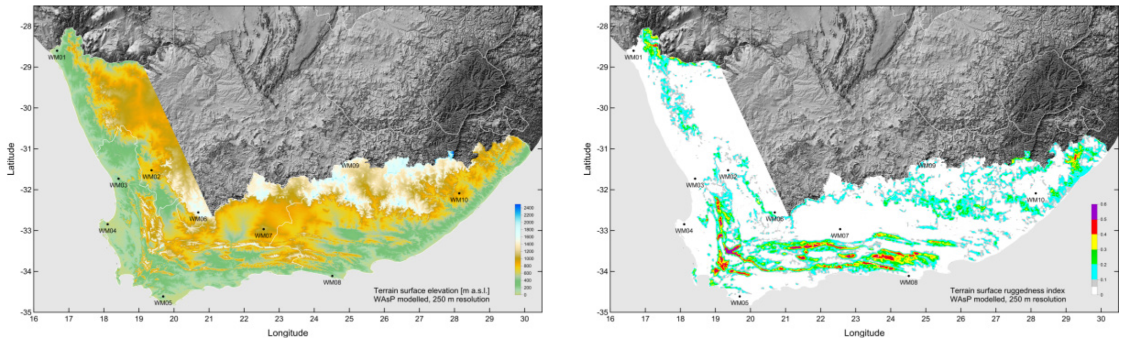

Figure 6. Mean terrain surface elevation (left-hand map) and ruggedness index (right-hand map) in the WASA domain. The results were obtained using WAsP 10; with model calculations for every 250 m.

The terrain surface elevation is the elevation (above sea level) derived by the WAsP flow model from the elevation database when performing the modelling for each point. It is included here as an independent measure of the accuracy and reliability of the resource mapping system.

The ruggedness index is a measure of the ruggedness (steepness) of the terrain and is included because it is directly related to the accuracy and reliability of the WAsP flow modelling. The ruggedness index is calculated using WAsP standard parameters.

4 Verification

Modelling results obtained in the WASA project are verified by comparison to similar results obtained at the ten measurement masts. The locations of the masts are indicated in Figure 3 and subsequent maps.

For the present application, the numerical wind atlas data sets and the wind resource mapping procedure were both tested at the 10 mast sites, see Figure 7.

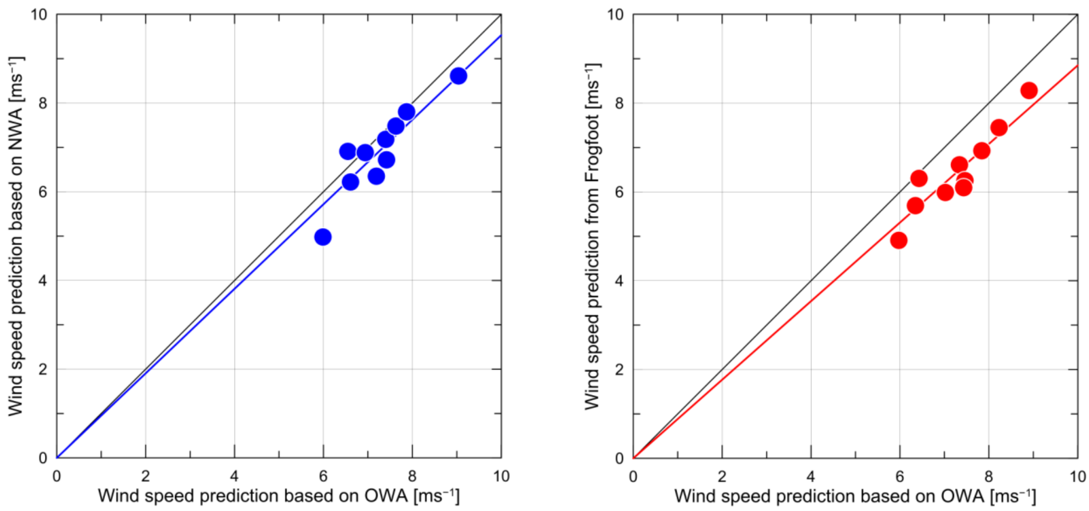

Figure 7. Verification against wind measurements @ 10 WASA masts. NWA and OWA are short for numerical and observation-based wind atlases, respectively. See text for further explanation.

In the left-hand graph, the numerical wind atlas data sets are tested separately. The wind atlas data set closest to each mast site is used to make a prediction of the mean wind speed at 80 m a.g.l. at the mast site using WAsP (*y*-axis). These speed values are then compared to what has been measured in the same period at the mast, extrapolated to 80 m a.g.l. using WAsP (*x*-axis). This is therefore a separate test of the wind-climatological inputs derived from the KAMM modelling.

On average, the mean wind speeds predicted by KAMM/WAsP are about 5% to low, with a standard deviation of about 6%. The largest differences are at met. mast WM01 (−13%) and mast WM02 (+5%).

In the right-hand graph, we test the final WAsP wind resource mapping results (here codenamed Frogfoot). The resource mapping points closest to the mast sites are used for the comparison. Here, we know the mean wind speed at 100 m a.g.l. from the resource map (*y*-axis). On the *x*-axis we show the WAsP prediction for the same site and height, based on measurements from the same period. This is therefore a test of both the numerical wind atlas inputs and the wind resource mapping, i.e. the elevation and roughness maps.

On average, the mean wind speeds predicted by the WAsP Resource Mapping System seem to be about 12% too low, with a standard deviation of about 5%. Around 5% of the bias comes from the numerical wind atlas data and about 7% from the microscale modelling, possibly related to the roughness map. No attempt has been made to remove these biases in the present data base of distributed results.

5 Applications

This new data base of large-scale, high-resolution wind resource estimates for the WASA domain has been designed for general planning purposes, strategic environmental assessment and wind farm planning and development.

The data base has already been employed by the Department of Environmental Affairs and Development Planning, Provincial Government of the Western Cape – and by the Department of Environmental Affairs – for GIS-based strategic environmental assessments (SEA) for the Western Cape Province and for the entire WASA domain, respectively. This work was presented recently in South Africa [8].

The data can also be used for some aspects of wind farm planning and development, e.g.

- Identification and ranking of potential wind farm sites
- Initial analyses and project design
- Project planning
- Pre-feasibility studies
  - Resource assessment
  - Some site assessment
- Design of measurement campaigns
  - Number and siting of masts
  - Orientation of sensor booms
  - Mounting of lightning rod and navigation lights

However, it should be borne in mind that the data base was designed specifically for planning purposes and should be used with utmost care for design, development and detailed assessments of actual wind farms; where local, on-site measurements are strongly recommended.

6 Conclusions

The wind resources over a large region in South Africa have been modelled with very high resolution using the WAsP microscale model – a fairly rare example of the very last step of the model chain: down to the microscale over very large areas. Inputs to the modelling were a verified numerical wind atlas produced as part of the WASA project, and readily available topographical data for South Africa.

The model setup that has made this approach possible is known as the WAsP Resource Mapping System, an automated implementation of WAsP based on databases rather than files. The modelling results have been validated at ten locations with high-quality meteorological masts and it was found that the present wind resource database provides conservative results.

The wind resource maps and data described here are subject to change without notice if and when more accurate and reliable data, models and procedures become available. The next steps have already been planned and consist of a WRF-based numerical wind atlas, as well as updated and more detailed topographical inputs to the modelling.

All data and results of the Wind Atlas for South Africa project are in the public domain and can be downloaded from the WASA web sites. An updated version of the detailed wind resource map will be available in the spring of 2014.

Acknowledgements

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References

1. Mortensen, N.G., J.C. Hansen, M.C. Kelly, E. Prinsloo, E. Mabille and S. Szewczuk (2012). Wind Atlas for South Africa (WASA) – Station and Site Description Report. Council for Scientific and Industrial Research (CSIR) and Department of Wind Energy, Technical University of Denmark (DTU). October 2012, 69 pp.

2. Frank, H.P., O. Rathmann, N.G. Mortensen and L. Landberg (2001). The numerical wind atlas – the KAMM/WAsP method. Risø-R-1252(EN). 60 pp.

3. Badger, J., N.G. Mortensen and J.C. Hansen (2006). The KAMM/WAsP Numerical Wind Atlas – A powerful ingredient for wind energy planning. In: Proceedings *Great Wall World Renewable Energy Forum and Exhibition*, Beijing, 23-27 October 2006.

4. Hansen, J.C., N.G. Mortensen, J. Badger, N.-E. Clausen and P. Hummelshøj (2007). Opportunities for wind resource assessment using both numerical and observational wind atlases – modelling, verification and application. In Proceedings of *Wind Power Shanghai* 2007, Shanghai (CN), 1-3 Nov 2007, p. 320-330.

5. Mortensen, N.G., J.C. Hansen, Z. Yang and Y. Luo (2008). Mesoscale and microscale modelling in NE China. In Proceedings of *Global Wind Power 2008*, Beijing (CN), 29-31 Oct 2008.

6. Mortensen, N.G., D.N. Heathfield, O. Rathmann and Morten Nielsen (2012). Wind Atlas Analysis and Application Program: WAsP 10 Help Facility. Wind Energy Department, Technical University of Denmark, Roskilde, Denmark. 356 topics.

7. Mortensen, N.G., J.C. Hansen, M.C. Kelly, S. Szewczuk, E. Mabille and E. Prinsloo (2012). Wind Atlas for South Africa (WASA) – Observational wind atlas for 10 met. stations in Northern, Western and Eastern Cape provinces. Council for Scientific and Industrial Research (CSIR) and Department of Wind Energy, Technical University of Denmark (DTU). October 2012, 44 pp.

8. Cornelius van der Westhuizen (2012). Methodology and initial results of the DEA wind Strategic Environmental Assessment. Windaba *2013 Conference and Exhibition*, Cape Town, see www.csir.co.za/nationalwindsolarsea